CHAPTER

4

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INTRODUCTION

Welcome to the metric system. Most of us will be using the simple term "metric" to describe a rather detailed set of rules known formally as the *Systeme Internationale* or International System of units (SI). There are several variations of the system and all have much in common. The version known as SI is the one most trusted by highway agencies in this country.

The original metric system was proposed and adopted by the French during the time of the French Revolution and rapidly spread throughout Europe during the Napoleonic wars. Its use was first proposed in the United States by Thomas Jefferson and later by John Quincy Adams. In 1866 Congress authorized its use as a measurement system in the United States.

Recent enactment of several federal laws has renewed the interest in the widespread use of the metric system in this country. Executive Order No. 12770 signed by President Bush on July 25, 1991 requires that all federal agencies implement the use of the metric system. Subsequently, the Federal Highway Administration, which authorizes federal aid to LA DOTD, has established a plan and schedule for converting to metric. **Our deadline is October 1, 2000**. Changing to metric will not be as difficult as you might expect. Other nations did not find it to be difficult. Every engineer's college studies included some training in metric, and many now work exclusively with metric. The Department has already adopted several national and international metric standards. These include some standards which have been in existence and use for many years such as those of the American Society of Testing Materials (ASTM) and the American Association of State Highway and Transportation Officials (AASHTO). Additionally, many DOTD materials tests are already conducted in metric measurements.

BRIDGE DESIGN SECTION POLICIES

1. For reasons of uniformity and consistency, the following note will be added to the General Notes for all construction and required standard plans. **"ALL DIMENSIONS ARE IN MILLIMETERS (mm) UNLESS OTHERWISE NOTED".**

2. **Centimeter dimensions** will not be used.

3. **Kilogram (kg)** is the base unit of mass, which is the unit quantity of matter independent of gravity.

4. All new surveys will be prepared using metric measurements, unless instructed otherwise by the Department.

5. Foreslope and backslope ratios will be expressed as **rise/run,** example **1:3.**

6. **1000 m or km stationing** will be used for metric plans.

7. **Radius** definition of curves will be used.

8. **Angular measurements** shall continue to be made in degrees, minutes, and seconds.

9. **Length conversion.** In converting feet to meters, it should be noted there are two definitions of the foot in the metric system. They are:

   a) The international foot is defined as exactly 0.3048 meters.

   b) The U.S. Survey foot is defined as $1200 \div 3937$ m, which is 0.30480060960. By law, the Louisiana DOTD must use the U.S. Survey foot definition.

BASIC METRIC INFORMATION

The metric system is formally referred to as the International System of Units or *Systeme Internationale* (SI), and it is acceptable to use the terminology interchangeably.

To help you get started in the metric system, here are some of the fundamental items that you should know.

Meter (m): The basic unit for measurement of length in the metric system is the meter. The meter is slightly longer than a yard and is generally used for measuring short distances. The length of a football field is approximately 91 m.

Kilometer (km): The metric unit that is generally used to denote longer distances is the kilometer. The kilometer is equal to 1000 m and is slightly longer than 0.6 miles.

Millimeter (mm): The metric unit that is often applied to the measurement of small distances or thickness is the millimeter. The millimeter is equal to one-thousandth of a meter, or 0.001 m. An inch is approximately 25 mm. Have you ever used any 35 mm film in your camera?

Square meter (m^2): The unit commonly used for the measurement of area is the square meter. A square meter is approximately 20% larger in area than a square yard. A room that is ten feet long and ten feet wide has a floor area of approximately 9 m^2.

Hectare (ha): The unit of measurement commonly used to express the area of bodies of land or water is the hectare. A hectare is equal to 10 000 m^2, which is approximately 2.5 acres.

Cubic meter (m^3): The unit of volume in the metric system is the cubic meter. The cubic meter has approximately 30% more volume than a cubic yard.

Liter (L): The unit that is used for the measurement of liquids or gases is the liter. The liter is defined as the volume occupied by the mass of a kilogram of pure water at 4°C (its maximum density under normal atmospheric pressure). A liter is slightly more than a quart. Have you ever purchased a soft drink in a 2 liter bottle?

It should be noted that a liter is also equivalent to one-thousandth of a cubic meter (0.001 m^3).

Gram (g): The unit most commonly used to express the mass of small items is the gram. A gram is equivalent to one-thousandth of a kilogram, or 0.001 kg. The mass of a penny is approximately 3 g.

Kilogram (kg): The basic unit that is used to express the mass of an item is the kilogram. This unit is commonly used to express the mass of large items such as televisions and refrigerators. A kilogram is approximately 2.2 pounds.

It should be pointed out that what is commonly referred to as "weight" in our current system of units is defined as "mass" in the metric system. For example, an individual or item that "weighs" 150 pounds has a mass of approximately 68 kg.

Megagram (Mg): The unit commonly used to express the mass of very large items or quantities is the Megagram. The metric ton is equivalent to 1000 kg.

Newton (N): The newton is the basic unit of force that is required to accelerate a mass of one kilogram at a rate of one meter per second per second, and is denoted by the formula $kg \cdot m/s^2$. This acceleration is commonly referred to as the acceleration of gravity.

It should be pointed out that the descriptive terminology "weight" as currently applied to an individual or an object is in fact the result of the acceleration due to gravity that is acting upon the "mass" of the individual or object. The same object on the earth's surface and on the moon's surface would have the exact same mass, but on the moon, the object would weigh much less due to the much lower acceleration of gravity on the moon. This phenomenon is due to the force of gravity, which is equal to the mass of an object multiplied by the acceleration of gravity. In the metric system, the acceleration of a body due to the earth's gravity at sea level is 9.81 m/s^2.

Second (s): The second is the fundamental unit of time and is the same unit as currently used in everyday terminology.

Temperature (°C): The metric unit that is widely used in the measurement of temperature is the degree Celsius (°C). On a hot summer day, when the temperature is normally expressed as 95°F (Fahrenheit scale), the metric equivalent would be 35°C.

Velocity (km/h): Velocity, or speed, is expressed in kilometers per hour (km/h). A residential speed limit of 25 miles per hour (mph) is approximately 40 km/h.

Pascal (Pa): The basic unit of pressure or stress in the metric system is the pascal. The pascal is the pressure or stress of one newton per square meter of area.

A typical automobile tire pressure of 35 pounds per square inch (psi) is approximately equal to 241 000 Pa, or more appropriately 241 kPa (kilopascals). A typical value of concrete compressive strength is 3000 psi, which is approximately equal to 20 000 000 Pa, or more appropriately 20 MPa (megaPascals).

BUILDING BLOCKS FOR SI UNITS

SI Base Units

Base Units	Units	Symbol
length	meter	m
mass	kilogram	kg
time	second	s
temperature	Celsius	°C
electrical current	ampere	A
luminous intensity	candela	cd
amount of material	mole	mol
Supplementary Units	**Units**	**Symbol**
angles in the plane	deg, min & sec	°, ', "
solid angles	steradian	sr

Prefixes

Sub multiples			Multiples		
deci	10^{-1}	d	deka	10^{1}	da
centi	10^{-2}	c	hecto	10^{2}	h
milli	10^{-3}	m	kilo	10^{3}	k
micro	10^{-6}	µ	mega	10^{6}	M
nano	10^{-9}	n	giga	10^{9}	G
pica	10^{-12}	p	tera	10^{12}	T
femto	10^{-15}	f	peta	10^{15}	P
atto	10^{-18}	a	exa	10^{18}	E
zepto	10^{-21}	z	zetta	10^{21}	Z
yocto	10^{-24}	y	yotto	10^{24}	Y

NOTE: AASHTO DOES NOT USE DECI, CENTI, DECA & HECTO UNITS.

Derived Units with special names

Quantity	Name	Symbol	Expression
frequency	hertz	Hz	s^{-1}
force	**newton**	**N**	**kg·m/s²**
pressure, stress	**pascal**	**Pa**	**N/m²**
energy, work, heat quantity	**joule**	**J**	**N·m**
power, radiant flux	watt	W	J/s
electric charge, quantity	coulomb	C	A·s
electric potential	volt	V	W/A
capacitance	farad	F	C/V
electric resistance	ohm	Ω	V/A
electric conductance	siemens	S	A/V
magnetic flux	weber	Wb	V·s
magnetic flux density	tesla	T	Wb/m²
inductance	henry	H	Wb/A
luminous flux	lumen	lm	cd·sr
illuminance	lux	lx	lm/m²

PHILOSOPHIES OF CONVERSION

Conversion from the English system of measurement to SI is an important topic for the transition period. It affects standards, specifications, guidelines, numerical regulatory limits, and manufacturing. There are two philosophies of conversion which may be applied in a given circumstance:

1. **Soft Conversion:** Direct mathematical conversion. The physical dimensions of a standard or product is unchanged, only the numerical value changes. For products this results only in changing of the label.

   Examples: A 55 mph speed limit becomes 88.514 km/h.
   A 12 foot lane becomes a 3.6576 m lane.

2. **Hard Conversion:** Converting to an nominal number. Results in changing product size as well as label.

   Examples: A 55 mph speed limit becomes 90 km/h.
   A 12 foot lane becomes a 3.6 m lane.

For a transition period it will be necessary to convert existing English quantities into the equivalent SI units. The following Conversion Factors Tables summarize several conversion factor useful in highway engineering.

USEFUL CONVERSION FACTORS

QUANTITY	FROM ENGLISH UNITS	TO METRIC UNITS	MULTIPLY BY*
length	mile	km	1.609347
	yard	m	0.914401
	foot	m	0.304800
	inch	mm	25.40005
area	square mile	km^2	2.590
	acre	m^2	4047
	acre	hectare	0.4047
	square yard	m^2	0.8361
	square foot	m^2	0.09290
	square inch	mm^2	645.2
volume	acre foot	m^3	1233
	cubic yard	m^3	0.7646
	cubic foot	m^3	0.02832
	cubic foot	L (1000 cm^3)	28.32
	1000 board feet	m^3	2.360
	gallon	L (1000 cm^3)	3.785
	cubic inch	cm^3	16.39
mass	lb	kg	0.4536
	kips (1,000 lb)	metric ton (1000 kg)	0.4536
mass/unit length	plf	kg/m	1.488
mass/unit area	psf	kg/m^2	4.882
mass density	pcf	kg/m^3	16.02
force	lb	N	4.448
	kip	kN	4.448
force/unit length	plf	N/m	14.59
	klf	kN/m	14.59
pressure, stress,	psf	Pa	47.88
modulus of elasticity	ksf	kPa	47.88
	psi	kPa	6.895
	ksi	MPa	6.895
bending moment, torque, moment of force	ft lb	$N \cdot m$	1.356
	ft kip	$kN \cdot m$	1.356

* SIGNIFICANT FIGURES

USEFUL CONVERSION FACTORS

QUANTITY	FROM ENGLISH UNITS	TO METRIC UNITS	MULTIPLY BY*
moment of mass	lb · ft	kg · m	0.1383
moment of inertia	lb · ft^2	kg · m^2	0.04214
second moment of inertia	in^4	mm^4	416 200
section modulus	in^3	mm^3	16 390
power	ton (refrig)	kW	3.517
	Btu/s	/W	1.054
	hp (electric)	W	745.7
	Btu/h	W	0.2931
volume rate of flow	ft^3/s	m^3/s	0.02832
	cfm	m^3/s	0.0004719
	cfm	L/s	0.4719
	mgd	m^3/s	0.0438
velocity, speed	ft/s	m/s	<u>0.3048</u>
acceleration	f/s^2	m/s^2	<u>0.3048</u>
momentum	lb · ft/sec	kg · m/s	0.1383
angular momentum	lb · ft^2/s	kg · m^2/s	0.04214
plane angle	degree	rad	0.01745
		mrad	17.45

* 4 SIGNIFICANT FIGURES; UNDERLINE DENOTES EXACT CONVERSION

RULES FOR WRITING METRIC

1. Print unit symbols in lower case except for liter (L) and megagram (Mg) or unless the unit name is derived from a proper name **(example: meter (m), kilogram (kg), newton (N), volt (V)).**

2. Print unit names in lower case, even those derived from a proper name. The first letter of a unit name is not capitalized except at the beginning of a sentence or in a capitalized material. **(exception: Always capitalized the word <u>Celsius</u> or the abbreviation for it, (C)).**

3. Print decimal prefixes in lower case for magnitudes ≤ 10^3 and print prefixes in upper case for magnitudes ≥ 10^6 **(example: kilometer (km), millimeter (mm), megaliter (ML))**

4. Leave a space between numeral and symbol **(example write 45 kg not 45kg).**

5. Do not leave space or hyphen between prefix and unit name. **(example write kilometer not kilo-meter or kilo meter)**

6. Do not leave a space between a unit symbol and it's decimal prefix **(example write km not k m)**

7. For area and volume quantities only, use the power modifier before the unit name **(example: cubic meter, square meter).**

8. For technical writing, use symbols in conjunction with numerals **(example: the area is 10 m^2)**; write the unit names if numerals are not used **(example: Area of wearing course is measured in square meters).** Numerals may be combined with written unit names in non-technical writing, **(example, 10 meters).**

9. Do not use the plural of unit symbol **(example: write 45 km)** but do use the plural of written unit names **(example: write 45 kilometers)**

10. Do not mix names and symbols **(example: write N·m or Newton meter, not N·meter)**

11. Do not use a period after a symbol, except when it occurs at the end of a sentence. **(example: write "12 g", not "12 g.").**

12. When text appear in dimensions, show units when needed for clarity. **(example: write B1002 @ 150 mm spaces.**

13. Use a zero before the decimal for values less the one **(example: write 0.45 m, not .45 m).**

14. Use spaces instead of commas to separate blocks of three digits, counting from the decimal point to both the right and left, for any number over **four** digits **(example: write 45 138 m, or 0.000 446 kg)**. Note that this does not apply to the expression of amounts of money. **(example: write $ 6,000,000.00)** or when used in formulas.

15. When compound units are formed by multiplication, leave space between unit names **(example: write Newton meter)**; however, when using unit symbols, indicate the product by placing a dot between symbols **(example: write N·m)**.

16. When dividing two units use **"per"** between the numerator and denominator **not "/"** or **"p"** if written out. **(example: kilometer per hour not kilometer/hour)** If symbols are used use the **"/"** and not **"p"**. **(example: km/h not kmph).**

17. Never use fractions, always use decimals. **(example: write 0.75 m, not ¾ m)**

18. Indicate the product of two or more units in symbolic form by using a raised dot. **(example: kg·m)**

19. 1000 m stations should be shown as follows; **(example: 34+192.300).**

PRECISION AND ROUNDING

Conversion to SI is a good opportunity to highlight the topics of precision and rounding. However, it must be emphasized that these are not topics unique to SI. Precision of a measurement refers to the degree of mutual agreement between individual measurements such that they are reproducible. Rounding refers to the process of reducing the number of significant digits in a quantity to those appropriate for representing the precision of a quantity. In a unit system such as the English system, we are constantly converting from feet to inches, from horsepower to watts, and others. The rules of precision followed on those occasions should also be followed when converting from English to metric units or from mass (in kilograms) to force of gravity (in newtons). Two rules are available:

Primary Rule:

Maintain precision of a measurement. This must always be achieved.

General Rule:

When implementing the primary rule, it is often effective to round the value to the same number of significant digits. This will approximately give the same implied precision. When maintaining the same number of significant digits provides misleading information on precision, the primary rule overrides the general rule.

Example where general rule applies; 5.2 miles at 1.609 km/mi = 8.369 km = 8.4 km.

Example where primary rule governs; 8.6 miles at 1.609 km/mi = 13.837 km = 13.8 km.

The highway engineer is already familiar with the notion of precision. The engineer reports a value, such as 5.2 miles, and there is an implied level of accuracy or precision. 5.2 miles implies a number between 5.15 and 5.25. When converting to metric, this same precision rule should be followed. Generally speaking, it is a good idea to round the metric value off to the same number of significant digits as the former example shows. The latter example shows this is not always the case. In order to maintain precision, the result has three significant digits instead of two.

If a quantity is described by more than one unit, then convert to the smaller unit before converting to metric. This will also cause the metric value to reflect the accuracy that was implied in the original value. For example, if a measurement is provided as 6 feet 4½ inches, it should be converted to metric in two steps. First, it equivalence in inches must be found as 76.5 inches. Then, it can be converted to metric using the appropriate conversion factor as follows (note only three significant figures are retained):

76.5 inches x 25.4 mm/inch = 1943.1 mm to 3 significant figures = 1940 mm.

The procedures for rounding are generally familiar to most technically trained personnel and are summarized below. The rules presented here are those specified in ASTM E380-92a.

Round up if the next digit is larger or down if the next digit is less than 0.5.

Examples: 43.87 mm → 43.9 mm

279.4 K → 279 K

If the number is exactly 0.5, then round up only if it makes the digit an even number.

Examples: Round up 77.5 J → 78 J

Round down 76.5 J → 76 J

REFERENCE MATERIAL

a) AASHTO "A policy on Geometric Design of Highways and Streets, 1994"

b) Standard Metric Practice Guide, AASHTO Designation: R1-91 or
ASTM Designation: E380-92a